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Smart Products: Conceptual Review, Synthesis, and Research Directions*

Stefan Raff, Daniel Wentzel, and Nikolaus Obwegeser

Smart products have received increasing attention from researchers and practitioners alike. One limitation of the existing literature, however, is that the term is often used as a blanket term and that there is no consensus on what a smart product actually is. Because different studies rely on differing conceptualizations, the current body of knowledge is scattered and lacks a uniform language and conceptual boundaries. Specifically, existing research has subsumed inherently different products under one collective term, has relied on a multitude of ad hoc criteria to define smart products or has conflated smart products with the services they render and/or the wider ecosystem, in which they operate. These developments limit the systematic advancement of the field and impede the integration of the smart product concept into related concepts such as the Internet of Things. To address these issues, this article provides an extensive analysis of the status quo of the field, with the goal of developing a common language and comprehensive conceptualization of smart products. First, existing studies on smart products were systematically reviewed across contributing disciplines and supplemented with a bibliometric analysis that allowed for a deeper understanding of the smart product concept within and across disciplines. This analysis revealed an initial set of 16 capability-based criteria that are currently applied to conceptualize smart products. Second, based on a systematic coding procedure, these criteria were synthesized and organized within a comprehensive framework delineating four distinct product archetypes for the digital age: (1) Digital, (2) Connected, (3) Responsive, and (4) Intelligent. Third, three major conceptual themes that arise from this framework are identified and possibilities for future research are pointed out. In sum, this work contributes to the literature by improving the understanding of smart products as an epistemic object and by laying the ground for more cumulative research endeavors.

Practitioner Points

- The analysis can be used to navigate in the areas of smart products and IoT as well as to leverage a firm's internal understanding of what smart products are and how smart products can be conceptualized as distinct archetypes.
- The proposed framework can help to understand how physical and virtual components of a product have to be orchestrated to perform certain functions and services and which requirements need to be fulfilled to lift a product to a more advanced level.
- Practitioners may use the framework to decompose value creation at the level of components and functions in order to develop an optimal architecture of a smart product's hardware and software as well as to derive effective pricing models.

Address correspondence to: Stefan Raff, RWTH Aachen University, TIME Research Area, Chair of Marketing, Kackertstraße 7, 52072 Aachen, Germany, E-mail: raff@time.rwth-aachen.de
Daniel Wentzel is co-corresponding author.
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Introduction

In the past decade, the term "smart product" has been buzzing around among technology experts, academics, and politicians alike. In their early days, smart products were mainly the subject of philosophizing in technology think tanks or were used for marketing cutting-edge technology at trade fairs. However, driven by advancements in technology, smart products have become a tangible reality and in some instances have already contributed to the disruption of traditional markets in the dawn of a new era, namely that of the Internet of Things (IoT) and technologized marketing and innovation (Brock, 2019; Ng and Wakenshaw, 2017).

The term itself has gained inflationary popularity-in-use among practitioners, and scholarly research shows a keen interest in the concept (Shim et al., 2019). A recent guest editorial in the *Journal of Product Innovation Management* (*JPIM*) once more underlines the significant role of IoT and smart products as "hot-topics" and cutting-edge fields of research (Bstieler et al., 2018). However, extant research about smart products is based on increasingly unstable ground: Despite the popularity of smart products as a field of research, in many respects there is no real consensus or clarity about what a smart product actually is.

First, research from the field of smart products has summarized inherently very different products under one collective term. For instance, Hoffman and Novak (2017) subsume the Philips Hue smart lights, the Amazon Echo, and the self-driving car under the term "smart object," whereas Rijsdijk and Hultink (2009) refer to car navigation systems, digital cameras, and mobile phones as "smart products." In a somewhat similar vein, scholars have also used a variety of terms more or less synonymously. For example, Novak and Hoffman (2018), Kortuem, Kawsar, Sundramoorthy, and Fitton (2010) and López, Ranasinghe, Patkai, and McFarlane (2011) refer to "smart objects." Touzani, Charfi, Boistel, and Niort (2018) discuss "connected objects" and Ng and Wakenshaw (2017) introduce the term "internet-connected constituents." In turn, Herterich and Mikusz (2016) employ the term "digitized artefact," while Langley et al. (2020) use the term "smart thing." Problematically, there are even studies using several of these terms within the same work without differentiating one from another (e.g., Mani and Chouk, 2017; Porter and Heppelmann, 2014). This ambiguity is compounded by the fact that other concepts exhibit overlaps with the smart product but need to be clearly distinguished in a conceptual sense. Prominent examples are "ubiquitous computing," "ambient intelligence," and above all the "Internet of Things" (Oberländer, Röglinger, Rosemann, and Kees, 2017).

Second, there is no agreement on the definition and defining criteria of "smart products." Existing definitions are often based on bundles of seemingly arbitrary characteristics or capabilities. For instance, an early definition from Allmendinger and Lombreglia (2005) stresses that a product gets smart via built-in intelligence through awareness and connectivity. On the contrary, Porter and Heppelmann (2015) define three core elements: physical components, "smart" components, and connectivity components. Finally, a frequently used definition from Rijsdijk and Hultink (2009) conceptualizes smartness as a combination of the dimensions autonomy, adaptability, reactivity, multifunctionality, ability to cooperate, humanlike interaction and personality, and the scope to which a product possesses one or more of these dimensions. While some studies from the fields of information systems (IS), marketing, and innovation management rely on or at least refer to this definition (e.g., Herterich and Mikusz, 2016; Kuijken, Gemser, and Wijnberg, 2017; Novak and Hoffman, 2018; Schweitzer and van den Hende, 2016), other scholars use different definitions or defining criteria (e.g., Mayer, Volland, Thiesse, and Fleisch, 2011; Meyer, Främling, and Holmström, 2009; Wangenheim, Wünderlich, and Schumann, 2017) or come up with their own ad hoc conceptualizations (e.g., Bstieler et al., 2018).

Third, instead of focusing on the actual product and its arrangements, recent research efforts related to smart products have concentrated on their functions or created service offerings as well as the larger ecosystems, in which they operate (e.g., Beverungen, Müller, Matzner, Mendling, and vom Brocke, 2019; Langley et al., 2020; Ramaswamy and Ozcan, 2018; Wuenderlich et al., 2015). While this focus on the service aspect has generated valuable insights, it also risks conflating smart products as bundles of cyber-physical arrangements (i.e., as devices that combine hardware and software components in a particular manner) with

BIOGRAPHICAL SKETCHES

Dr. Stefan Raff is an assistant professor at RWTH Aachen University, Germany (Chair of Marketing, TIME Research Area). He holds a PhD in business administration from RWTH Aachen University. His current research interests include innovation management, services marketing, and consumer behavior in digital environments.

Prof. Dr. Daniel Wentzel is professor of marketing at RWTH Aachen University, Germany (Chair of Marketing, TIME Research Area). He holds a PhD in business administration from the University of St. Gallen, Switzerland. His research has been published in leading journals including *Journal of Marketing, Journal of the Academy of Marketing Science, Journal of Business Venturing, Journal of Service Research, International Journal of Research in Marketing, The Leadership Quarterly*, among others, and has been featured in various media outlets and business magazines. His current research interests include innovation marketing, product design, and consumer behavior in digital environments.

Dr. Nikolaus Obwegeser is a research fellow at IMD Business School, Switzerland. Nikolaus holds a PhD from the Vienna University of Economics and Business, Austria and formerly worked as associate professor for information systems at Aarhus University, Denmark. His areas of expertise include digital business transformation, innovation, and information systems. His recent works are published in various academic and practitioner outlets, including *MIT Sloan Management Review, Information Systems Management,* and *Technovation*. Nikolaus regularly provides advisory and consulting services for public and private organizations in the area of digital business transformation and innovation.

the outcomes that are afforded by these arrangements. Thus, in order to understand how smart products—either by themselves or as part of larger ecosystems—create value, one first needs to understand what smart products actually *are*.

In sum, the widely varying perspectives on smart products have led to a knowledge base that is scattered and patchy and consists of a broad array of disconnected research efforts. However, to enable fruitful research, it is crucial to ensure that the *epistemic object* as well as the terminology associated with this object are clearly conceptualized and defined (Rheinberger, 1997; Yadav, 2018). Since management science is a cumulative venture, the lack of a consensus definition and a precise language pose a severe threat to the development of a cumulative body of knowledge, impede the comparability of empirical findings as well as aggravate the link to other concepts (Astley, 1985; Keen, 1980; vom Brocke et al., 2009).

Moreover, if the understanding of smart products is to advance, it is not only important to achieve consensus as to what a smart product actually is, but also to distinguish smart products from related aspects such as the services and functions that they render or related concepts such as the Internet of Things in which they operate. In this respect, it is important to remember that a smart product is, in fact, a *product*, that is, a cyber-physical device that not only possesses software-based digital capabilities, but also has a distinct material nature. Being cognizant about this materiality is important because it affects how smart products create value, either by themselves or as part of larger ensembles, and how consumers relate to these products.

First, intelligent services (so-called smart services) are frequently wrapped around smart products (Allmendinger and Lombreglia, 2005). In many areas, devices collect, interpret as well as share data with a myriad of agents (Langley et al., 2020; Porter and Heppelmann, 2014; Ramaswamy and Ozcan, 2018). For example, a smart vacuum cleaner is equipped with built-in sensors that scan the environment and inbuilt actuators that perform the movement and cleaning. Additionally, it uses connectors and installed software for communicating with the consumer's smartphone. As this example shows, a distinct device equipped with sensors, connectors, and software is the key boundary object for delivering any services and functionalities (Beverungen et al., 2019). Hence, to understand how smart products create value within and beyond their material boundaries, it is important to develop a thorough conceptualization of the actual product as a bundle of cyber-physical arrangements.

Second, in the digital age, firms are racing to establish new forms of customer interaction or business models through the use of new technologies. Such technologies often collect large amounts of data that allow for the creation of personalized value (Hopp, Antons, Kaminski, and Oliver Salge, 2018; Reinartz, Wiegand, and Imschloss, 2019). For these business models to be viable and deliver sustainable benefits, it is necessary to build relationships with customers over extended periods of time. Importantly, however, these relationships are often formed on the basis of a cyber-physical entity. For example, while Apple may create value for its customers by delivering personalized recommendations, the behavioral data that is necessary for these recommendations can only be generated if customers engage with their iPhone or iPad on a daily basis. Hence, while smart services may become increasingly relevant, the provision of these services frequently requires that consumers build a relationship and engage with a physical device (Benamar, Balagué, and Zhong, 2020; Novak and Hoffman, 2018).

In sum, these arguments demonstrate that a rigorous debate on smart products that was repeatedly called for in *JPIM* (e.g., Barczak, 2016; Bstieler et al., 2018) can only be fertile if there is clarity, observability, and consensus about the *epistemic object* (i.e., being clear about what a smart product actually is) (Rheinberger, 1997; Yadav, 2018). In service of this objective, this research follows three interrelated research questions:

> *RQ1. What is the content of the current academic body of literature investigating smart products?*
>
> *RQ2. How can extant research be synthesized toward a standardized framework of reference for smart products?*
>
> *RQ3. What are the limitations of current research and promising avenues for future investigation?*

To answer the first research question, a two-part study was performed. First, as a crucial step toward delineating the existing definitions and descriptive elements of smart products, a cross-disciplinary systematic literature review (SLR) was conducted (Barczak, 2017; Webster and Watson, 2002). Similar to other novel domains that have benefitted from SLRs such as business models (e.g., Li, 2018), business model innovation (e.g., Foss and Saebi, 2017), or design thinking (e.g., Micheli, Wilner, Bhatti, Mura, and Beverland, 2018), a rigorous review of the literature on smart products helps to grasp the whole of this multifaceted and interdisciplinary concept (Rindfleisch, Mehta, Sachdev, and Danienta, 2020). Second, a supplementary bibliometric analysis was performed to provide structural insights into the evolution of different conceptualizations of smart products (Palmatier, Houston, and Hulland, 2018). This allowed representing the diverging understandings in a quantitative manner. In sum, these two steps revealed a scattered body of knowledge and allowed to dig deeper into the nature of the different understandings of smart products.

To answer the second research question, the different conceptualizations identified in the SLR were analyzed and standardized in a multistep coding procedure. The current knowledge base was systematically condensed and synthesized into a set of 16 capability-based definition criteria from which different hardware and software components emerged. In a next step, these criteria were further condensed and synthesized. This resulted in a framework that conceptualizes four different archetypes of smart products that are organized in a hierarchical framework and that are characterized by increasing levels of complexity and capabilities.

To answer the third research question, a number of "blind spots" and promising opportunities for future research were identified, using the conceptual framework as a point of reference. Specifically, three broad areas needing research attention are pointed out. First, if smart products can indeed be conceptualized as four different archetypes that are organized in a hierarchical fashion, then, future research will need to address how smart products evolve along with these archetypes and what the next future archetype will look like. Second, as smart products constitute bundles of cyber-physical arrangements, more research is needed to dissect the role of the material nature of smart products and to understand how this material nature shapes the value created by the products. Third, as smart products frequently serve as platforms from which a stream of software-based services can be launched, it will be important to understand how companies can derive an optimal architecture for the physical products as well as the associated software components.

Systematic Review of the Smart Product Literature

A systematic literature review (SLR) consists of the quest for relevant literature on a particular topic and involves the following three broad steps: data collection, analysis, and synthesis (Tranfield, Denyer, and Smart, 2003). The SLR in this article was guided by the widely accepted principles from Tranfield et al. (2003), vom Brocke et al. (2009), and Webster and Watson (2002). Specifically, a concept-centric literature review was pursued (Webster and Watson, 2002), which is best suited when attempting "to tackle an emerging issue that would benefit from the development of new theoretical foundations" (Paré, Trudel, Jaana, and Kitsiou, 2015, p. 188). An SLR needs to be systematic in terms of the methodological approach, explicit through a clear explanation and documentation of the steps pursued, comprehensive in its scope, and reproducible by others following the same steps (Templier, Paré, and Rowe, 2018; Webster and Watson, 2002). To fulfill these requirements, the following multistep approach to detect and select relevant sources was applied: (i) database search across different disciplines, (ii) title and abstract screening, (iii) content evaluation and quality appraisal, and (iv) backward and forward search. This process resulted in a final sample of 38 articles for in-depth content analysis (Bryman, 2016). Figure 1 provides an overview of the literature search and selection process.

Database Search across Different Disciplines

The Web of Science database (WoS) was considered to provide an adequate and comprehensive collection of relevant academic literature and was, therefore, used for the literature search. The overall structure of the literature search and filter process was broad and inclusive in nature, aiming at bringing together different streams of literature to comprehensively collect all articles that may contain smart product-related research (Paré et al., 2015). As the field of smart products is inherently interdisciplinary, the literature

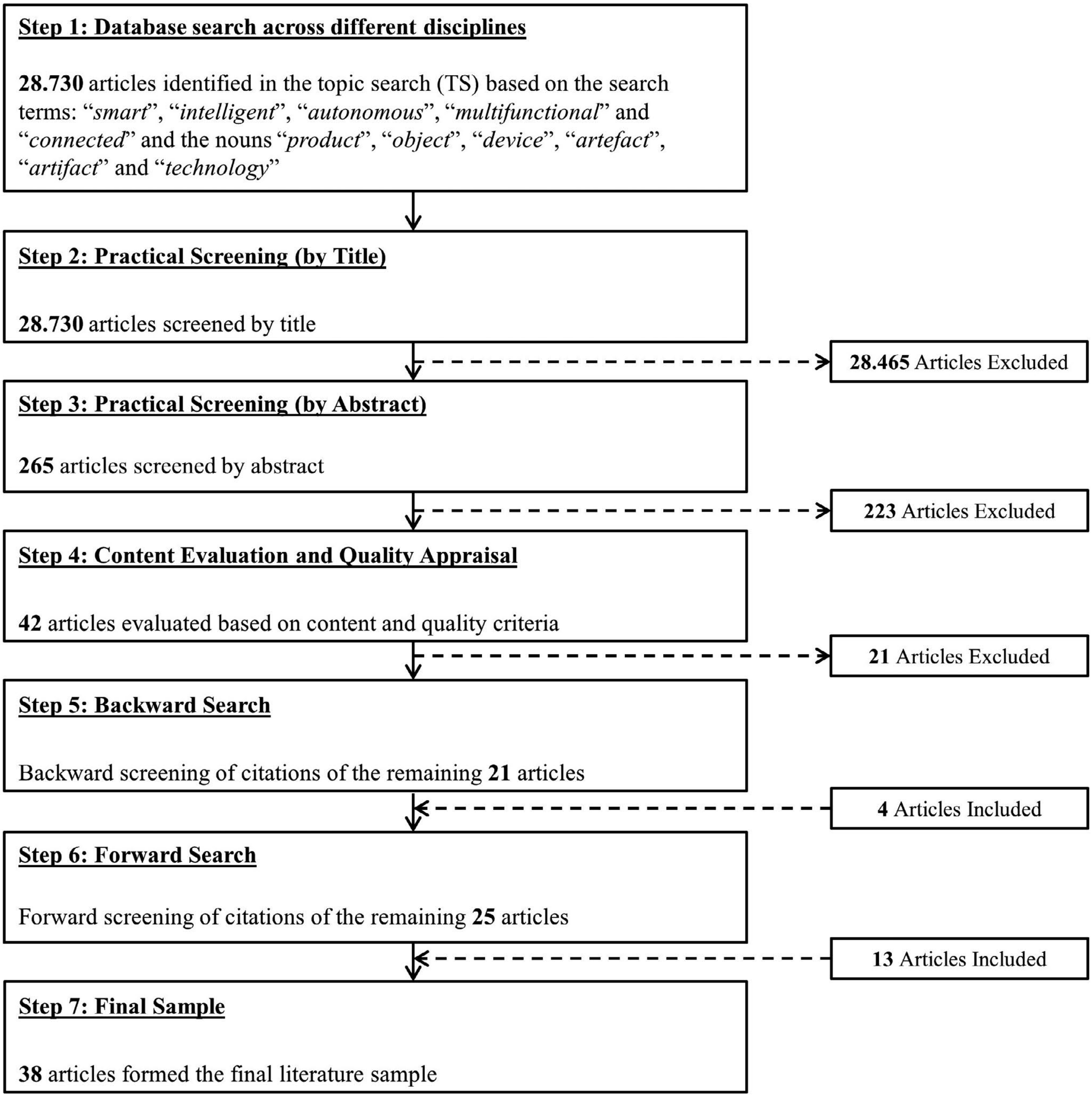

Figure 1. Flow Chart of the Literature Search Process

search was broad across all document types and business domains, including but not limited to—marketing, innovation, and information systems (IS) (Ng and Wakenshaw, 2017; Webster and Watson, 2002). To determine the timeframe for the primary search process, an initial check of the current literature was carried out, focusing on smart products and related topics such as ubiquitous and pervasive computing, smart technologies, and the IoT. Based on this, the period between 1998 and 2019 appeared to be a reasonable timeframe.

The final search string for the identification of the corpus of relevant literature was developed through an iterative process of reviewing extant literature and a lively exchange with experts from academia and practice. First, top-tier articles in the context of ubiquitous and pervasive computing, smart technologies, and the IoT were scanned to shed light on the potential keywords to be included in the search string. Second, discussions with experts from the field brought about further input, leading to a varied thesaurus of keywords evolving around the adjectives "smart," "intelligent," "autonomous," "multifunctional," and "connected" and the nouns "product," "object," "device," "artefact," "artifact," and "technology." Using these terms as search terms in the final search string resulted in 28,730 papers.

Practical Screening

In a first step, a manual cursory analysis of the articles based on title and abstract was pursued. This approach was inspired by recent reviews from the field that had faced equally large samples in their first search round (e.g., Micheli et al., 2018; Vries, Bekkers, and Tummers, 2015). This process resulted in 265 articles. Next, the abstracts of the 265 remaining articles were read thoroughly and, in the case of a promising abstract, also portions of the text to further narrow down the selection. In this process, the thematic positioning of each article was pivotal for the evaluation: articles that focused predominantly on specific technical aspects tended to be excluded if they did not cover smart products in their entirety. Since the aim of this work is a review of existing definitions, especially articles that attribute general properties to smart products were chosen. Studies that were limited to a specific product or product group, without drawing generalizable conclusions about smart products, were also excluded.

Content Evaluation and Quality Appraisal

Next, the 42 remaining articles were read and evaluated in terms of their content. Following this, a coding scheme was developed which contained detailed descriptive data, content summaries, and personal comments. In addition to the content, several quality criteria were considered for the inclusion of articles in the final sample, such as the rating of the source, the journal, or the conference proceeding, in which the article was published. The *Financial Times* (*FT50*) ranking and the German *Verband der Hochschullehrer für Betriebswirtschaft* (*VHB*) ranking were used for the evaluation of sources. Moreover, it was explicitly decided to include conference papers in the sample as an initial scan of the literature had revealed a number of conference papers that had become very influential in this research domain (e.g., Wong, McFarlane, Ahmad Zaharudin, and Agarwal, 2002). Many of the more recent contributions were first presented at conferences before going through the longer review cycles of journals. For the conference papers (henceforth also referred to as "article"), special attention was paid to considering—but not limited to—those that were presented at high-quality conferences such as the proceedings of the *Hawaii International Conference on System Sciences* (*HICSS*), *International Conference on Information Systems* (*ICIS*) or the *IFIP WG 8.6 pre-ECIS International Working Conference "Smart Working, Living and Organising" on Transfer and Diffusion of IT* (*TDIT 2018*). Based on the process described above, 21 articles were selected for the initial sample.

Backward and Forward Search

Conducting a backward and forward search via cross-references is particularly important for concept-centric literature reviews as it increases the completeness and reliability of the resulting literature list (Tranfield et al., 2003; vom Brocke et al., 2009). This step resulted in the identification of 17 additional articles, bringing the final literature list for in-depth analysis and data extraction to 38 articles. All articles from the final literature sample can be found in supplementary information Appendix A and are denoted by an asterisk in the reference list.

Sample Description

The chronological publication distribution of the reviewed literature is depicted in Figure 2. It shows the increasing body of knowledge after 2015, mirroring the emerging nature and growing relevance of the research field. 21% (8 of 38) of the articles from the final literature sample originate from the years 2002 until 2009. 79% (30 of 38) of the articles originate from the years 2010 until 2019. As can be seen, publications peak since the mainstream adoption of devices such as the Amazon Echo or Google Home Speaker. 29 articles from the sample are published in high-quality peer-reviewed journals (except *Harvard Business Review* (*HBR*) as a practitioner-oriented outlet). From a journal perspective, *JPIM* had the highest appearance in the sample (Bstieler et al., 2018; Mani and Chouk, 2018; Rijsdijk and Hultink, 2003, 2009) with four appearances, followed by *HBR* (Allmendinger

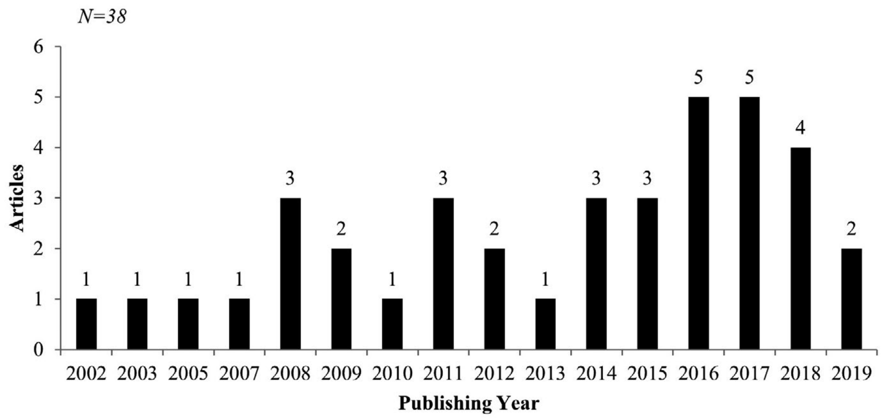

Figure 2. Year of Publication of the Articles in the Final Literature Sample

and Lombreglia, 2005; Porter and Heppelmann, 2014, 2015) with three appearances. Nine sources appeared in conference proceedings from the fields of IS and innovation management such as the *WI*, *HICSS*, and *ICIS*. From a conference perspective, *ICIS* proceedings had the highest appearance in the sample, contributing with two articles (Herterich and Mikusz, 2016; Püschel, Schlott, and Röglinger, 2016). The final sample includes 10 empirical and 28 theoretical contributions (see supplementary information Appendix A). Table 1 shows that the majority of the articles from the final sample (17) are based on ad hoc conceptualizations or own definitions for smart products, 13 articles use a definition that is based on a combination of descriptive elements from previously established definitions, and 8 articles base their definition on previously established ones which is a first indication of the field's noncumulative nature. Additionally, a brief analysis via the WoS citation analysis tool provided support for the inherently interdisciplinary nature of current smart product research (as of February 2020). As an example, the influential smart product articles by Rijsdijk and Hultink (2009) and Porter and Heppelmann (2014) from the innovation and marketing field received 14.4% and 10.3% of their overall citations from the IS domain.

Data Analysis and Coding

The in-depth review of the articles revealed the different defining characteristics and capabilities that form the basis of the current conceptualizations of smart products (Bryman, 2016). In most of the articles, the underlying understanding of what defines a smart product could be found in either the introduction section or the conceptual background section. Generally, only few definitions for smart products have found cumulative application in the sample through being re-cited (Table 1). One was introduced by Rijsdijk, Hultink, and Diamantopoulos (2007) (slightly adapted later on by Rijsdijk and Hultink (2009)). According to these authors, a smart product is characterized by the seven performance dimensions: *autonomy*, *adaptability*, *reactivity*, *multifunctionality*, *ability to cooperate*, *humanlike interaction*, and *personality* and "the extent to which it possesses each of these dimensions" (p. 342). An alternative re-cited definition was proposed by Porter and Heppelmann (2014) in *HBR* that characterizes smart products as a combination of the three elements *physical components*, *smart components*, and *connectivity components*. Moreover, these authors emphasize that smart products are enabled by the information technology (IT) that is embedded in physical objects, such as sensors, processors, software implementations, and connectivity modules that allow the storage of captured data in a product cloud. Finally, another re-cited definition is based on Wong et al. (2002) and describes an intelligent product as a physical product "that has part or all of the following five characteristics: (1) Possesses a unique identity, (2) Is capable of communicating effectively with its environment, (3) Can retain or store data about itself, (4) Deploys a language to display its features, production requirements etc., (5) Is capable of participating in or making decisions relevant to its own destiny" (p. 7).

Moreover, the examination of the literature revealed that authors often implicitly list the same

Table 1. Literature Sample: Research Domain, Research Perspective, and Respective Definition Approach

Article	Research Domain	Research Perspective	Ad hoc Conceptualization	Based on an Established Definition Suggested in a Previous Article (Authors)	Based on Combined Definitions
Wong et al. (2002)	IS	Organizational (O)	x		
Rijsdijk and Hultink (2003)	Inno & Mar	Consumer/User (CU)			x
Allmendinger and Lombreglia (2005)	Inno & Mar	O	x		
Rijsdijk et al. (2007)	Inno & Mar	CU/P	x		
Valckenaers and Van Brussel (2008)	Inno & Mar	Product (P)	x		
Maass and Varshney (2008)	IS	P		x (Maass and Jantzen, 2007)	
Mühlhäuser (2008)	IS	P	x		
Meyer et al. (2009)	IS	P			x
Rijsdijk and Hultink (2009)	Inno & Mar	CU		x (Rijsdijk and Hultink, 2002, definition equals Rijsdijk and Hultink, 2009)	
Kortuem et al. (2010)	IS	P	x		
Kiritsis (2011)		P/O			x
López et al. (2011)	IS	P/O		x (Wong et al., 2002)	
Mayer et al. (2011)	IS	CU			x
López et al. (2012)	IS	P	x		
Miorandi et al. (2012)	IS	P/O	x		
Gutierrez et al. (2013)	IS	P	x		
Pérez Hernández and Reiff-Marganiec (2014)	IS	P/O		x (Wong et al., 2002)	
Porter and Heppelmann (2014)	Inno & Mar	O/P/CU	x		
Meyer et al. (2014)	Inno & Mar	P/O			x
Porter and Heppelmann (2015)	Inno & Mar	O		x (Porter and Heppelmann, 2014)	
Dorsemaine, Gaulier, Wary, Kheir, and Urien (2015)	IS	P	x		
Whitmore et al. (2015)	IS	P/O	x		
Baird and Riggins (2016)	IS	O/P/CU	x		
Mani and Chouk (2017)	Inno & Mar	CU			x
Herterich and Mikusz (2016)	IS	P	x		
Schweitzer and Van den Hende (2016)	Inno & Mar	CU			x
Holler et al. (2016)	IS	O			x
Püschel et al. (2016)	IS	P			x
Ng and Wakenshaw (2017)	Inno & Mar	O/P/CU			x
González Garcia et al. (2017)	IS	P			x
Dawid et al. (2017)	Inno & Mar	O/P/CU	x		
Touzani et al. (2018)	IS	CU	x		

Table 1. Continued

Article	Research Domain	Research Perspective	Ad hoc Conceptualization	Based on an Established Definition Suggested in a Previous Article (Authors)	Based on Combined Definitions
Hoffman and Novak (2017)	Inno & Mar	CU			x
Bstieler et al. (2018)	Inno & Mar	O/P/CU	x		
Mani and Chouk (2018)	Inno & Mar	CU		x (Hoffman and Novak, 2015)	
Novak and Hoffman (2018)	Inno & Mar	CU		x (Rijsdijk and Hultink, 2009)	
Raff and Wentzel (2019)	IS	CU		x (Rijsdijk and Hultink, 2009)	
Chanson et al. (2019)	IS	O			x
Sum			17	8	13

defining criteria but name them differently. For example, "connectivity to other products" and "networking of smart products" both describe the Internet-based connection between objects, whereas "context-awareness" and "situatedness" both refer to some sort of real-time context-awareness. These findings point to a certain degree of commonality across different studies. That is, while a variety of authors have defined smart products in slightly different ways and have used a range of defining criteria, some of them are synonymous or used more regularly, suggesting a level of concurrence.

In order to allow for a systematic comparison of different definitions, it was necessary to standardize them first. To this end, a coding scheme for each article was developed and the definitions were decomposed into their constituent elements. Following this, inductive data coding was performed where sets of related codes were grouped into basic defining criteria (Boyatzis, 1998). For example, the descriptive properties "communicate with other equipment," "communicate with other objects," or "communication capabilities" were subsumed under the capability criterion "Communication and Information Exchange," which encompasses all communication and information exchange-related aspects of devices (see also Table 2).[1] The data coding was pursued by two independent scholars from the fields of marketing and innovation leading to a moderate interrater-agreement after the first round of coding (*Cohen's kappa* = .61; Cohen, 1960). After the coding, an initial set of 221 defining criteria was grouped into the following 16 capability-based definition criteria that are explained in detail in Table 2: *IT Equipped*, *Data Storage*, *Data Processing and Analysis*, *Data Provision and Transmission*, *Unique Identification*, *Networking and Connectivity*, *Communication and Information Exchange*, *Interaction and Cooperation*, *Sensing*, *Real-Time Context-Awareness*, *Reactivity and Adaptability*, *Automated Actuation*, *Functionality and Customization*, *Reasoning and Decision-Making*, *Autonomy and Self-Management*, *Proactivity*.

[1]Only explicitly mentioned criteria were included in the data coding although it may have occurred that authors implicitly considered further criteria. Thus, explicit criteria reflect aspects that authors specifically mentioned for the definition or characterization of smart products, whereas implicit criteria reflect properties that they may have additionally attributed to smart products in the course of an article.

Table 2. Capability-based Criteria, Codes, and Frequency of Occurrence

Criteria	Frequency	Code (Wording as Applied in Current Literature)[a]	Example Quote
(1) Digital			
IT equipped	18	Physical objects, equipped with sensors and actuators/Embedded operation system/Equipped with intelligence-generating technologies/Sensors and actuators embedded into everyday objects and devices/Products that contain IT/Physical and information-based representation of a product/ Object equipped with IT/Physical components and smart components/Digital and physical materiality/ Physical embodiment/Traditional industrial products and machines get empowered by digital technologies/(…) Incorporated in all manner of consumer objects/Everyday objects can be equipped with (…)	"Sensors that collect data, and actuators that transmit that data, are being increasingly incorporated in all manner of consumer objects commonly found in and around the home, worn on or in the body, and used in consumption activities involving shopping, entertainment, transportation, wellness, and the like" (Hoffman and Novak, 2017, p. 1178)
Data storage	12	Retention/Cloud storage/Storage/Store data/Data storageStore measurements/Store information/ Memory	"An intelligent product (…) 3. can retain or store data about itself (…)" (Wong et al., 2002, p. 2)
Data processing and analysis	18	Information processing/Data analysis/Diagnostic/Use the data/Processing/Transport/Process environment data/Aggregate data/Analyze data/Data processing/ Compute complex computations/These products can process and analyze user data/Transmit the data	"We see an intelligent product as a product system which contains (…) data processing, (…)" (Kiritsis, 2011 p. 480)
Data provision and transmission	13	Provision of identification and product information/ Access to the generated data by users or other systems/Are able to make their identification, sensor measurements, and other attributes available to external entities/Semantic self-description	"Smart Objects are those objects that are able to make their identification, sensor measurements, and other attributes available to external entities such as other objects or systems" (López et al., 2012 p. 295)
(2) Connected			
Unique identification	9	Unique identity/Uniquely identifiable/ Human-readable (object description)/The address is a machine-readable string/Can be identified throughout its life/Identify themselves/Make their identification/ Existence of a unique and immutable identity/Possess a unique identifier/Identifying	"(…) the core concept is that everyday objects can be equipped with identifying, (...) capabilities" (Whitmore et al., 2015, p. 261)
Networking and connectivity	22	Part of an infrastructure/Interact with the environment and other objects/Work together as assemblages/Communication networks/Network connectivity/Network connection to other devices/ One-to-one, one-to-many, Many-to-many connectivity/Connected constituents/Self-organized embedding into different (smart) environments/ Interoperate with other products	"(…) a system of uniquely identifiable and connected constituents (…)" (Ng and Wakenshaw, 2017, p. 6)
Communication and information exchange	20	Interfaces to exchange information with their environment/Communicate with other equipment/ Communicate with other objects/ Wireless communication technology/ Can communicate/Communicate with each other/ Report its location, condition, and/or state/ Able to communicate/Interchange information/ Communicate with other products/Communication functionalities/Communication capabilities	"Smart products show at least one of these characteristics. First, products become able to communicate with other products" (Rijsdijk and Hultink, 2003, p. 205)
Interaction and cooperation	18	Ability to cooperate/Interact with the environment and other objects/Interact with each other/ Interaction/Operate and interact with other devices/ Participating/Interaction with and along smart things/Interact with users/Ongoing interaction	"Smart products include those that can perform one or more of these tasks: collect and transmit user data, independently interact with users (…)" (Bstieler et al., 2018, p. 305)
(3) Responsive			
Sensing	24	Gather data/Collect data/Retain data/Data it collects/ location, condition or state capturing/Profiling and behavior tracking/Sensors/Sensing/Miniaturized Sensors/Able to sense/Status applications/Sensor data	"Smart Objects are those objects that are able to sense and store measurements made by sensor transducers associated with them" (López et al., 2012, p. 295)

Table 2. Continued

Criteria	Frequency	Code (Wording as Applied in Current Literature)[a]	Example Quote
Real-time context-awareness	5	Situatedness/Interaction by means of context-awareness/Use information about the environment in which they run/Business awareness	"In compliance with the above mentioned core requirements, smart products can be characterized by a framework with six general dimensions: 1. Situatedness: recognition of situational and community contexts; (…)" (Mass and Varsheny, 2008, p. 213)
Reactivity and adaptability	10	Adaptability/Alter its location, condition, and/or state/Adapt their actions to different situations/Independently/Improve their performance/Reactivity	"(…) the ability of a product to react to changes in its environment in a stimulus/response manner" (Rijsdijk et al., 2007, p. 342)
Automated actuation	6	Actuators/Influence condition or state of environment/Alter its location, condition, and/or state/Actuation/Miniaturized actuators	"(...) smart products have: (…) 'actuators' that activate an action (…)" (Mani and Chouk, 2017, p. 4)
Functionality & customization	3	Multifunctionality[b]/Personalization	"2. Personalization: tailoring of products according to buyer's and consumer's needs and affects" (Maass and Varshney, 2008, p. 213)
(4) Intelligent			
Reasoning and Decision-making	11	Reasoning/Can make decisions about themselves and their interactions/Making decisions/Participating in decisions	"Smart Objects are those objects that can make decisions about themselves and their interactions with external entities" (López et al., 2012, p. 295)
Autonomy and self-management	20	Act in an intelligent way and independently/Activate an action/Activate actions/Autonomy/Work fully autonomously/(Making decisions) relevant to its own destiny/Trigger actions/Self-organized/(Make decisions about) themselves/What can be done for them (consumers)	"(…) defined this construct (smartness) as consisting of seven dimensions: autonomy, (…)" (Rijsdijk and Hultink, 2009, p. 25)
Proactivity	4	Proactive behavior/Proactivity/Act proactively	"A Smart Product is an entity (…) providing improved simplicity (…) by means of (…) proactive behavior, (…)" (Mühlhäuser, 2008 p. 6)

[a]Codes are only provided if different terms as the derived final capability-based criterion were employed.
[b]Since products of all archetypes can often perform more than just one function, that is, are multifunctional, this criterion was considered to refer to devices whose functions can individually be configured or programmed by the user via skills, apps, routines or the like.

Bibliometric Analysis

To further explore the conceptual development of the smart product in current research, the SLR was supplemented with a bibliometric analysis (Palmatier et al., 2018). Specifically, the 16 derived capability-based definition criteria allowed for a quantitative comparison of existing conceptualizations of smart products on a standardized criterion level. In order to perform a meaningful bibliometric analysis on this level, a conformity measure was calculated that indicates the similarity or consensus of the conceptualizations used in the articles (Scheff, 1967). A criterion matrix that relates each article from the literature sample (rows) to the set of extracted criteria (columns) served as the starting point for the conformity measure (see supplementary information Appendix B). An "x" in a cell $a_{m,i}$ shows that the article of row m lists the criterion of column i in its smart product definition. The derived conformity score $CS(M,N)$ is based on the logic of the Jaccard similarity coefficient and relates the criteria-based intersection ($M \cap N$) of two definitions of article M and N to the union ($M \cup N$) of both papers (Jaccard, 1901; Leydesdorff, 2008):

$$CS(M,N) = \frac{|M \cap N|}{|M \cup N|}$$

Thus $CS(M,N)$ represents the ratio between the number of commonalities and the sum of the overall considered properties of two papers that allows determining the degree of consensus in the article sample. $CS(M,N)$ is calculated according to $\forall m = 1, \ldots, M$ and

$\forall n = 1, \ldots, N$, with $M = N = 38$ representing each possible pairing of papers. $CS(M, N)$ may range from 0% (no conceptual unity at all) to 100% (complete conceptual unity).

Figure 3 plots the development of the conformity scores over time and maps the relevant publication points of the articles from the innovation and marketing field (Inno & Mar). Overall, the findings from the bibliometric analysis provide support for the initial observation of a scattered and patchy body of research suffering from a lack of consensus regarding what defines a smart product. The overall mean score across the papers of the sample oscillates between rather low conformity levels of 21.7% and 31.0% over the considered time span, averaging on the level of 26.7% (SD = 2.7%). These numbers are a witness to the conceptual disagreement prevailing in the field. In addition, the analysis of the conformity scores allowed for an intra-disciplinary analysis, comparing the literature sample on the level of the research field. Figure 3 shows that the average conformity score of the IS field (m = 43.1%; SD = 10.8%) runs above that of the innovation and marketing field (m = 20.8%; SD = 4.7%), suggesting higher consensus regarding the conceptualization of smart products. However, these numbers have to be interpreted with caution as two articles from the beginning of the observation period (i.e., Meyer et al., 2009; Wong et al., 2002) have relied on very similar conceptualizations, thus affecting the field's overall conformity score. In sum, the scores for both research streams range at low levels and converge over time. In addition, Pearson correlation coefficients were computed to assess the relationship between the development of the total body of knowledge (cumulated number of articles in the sample) and the respective conformity scores of the IS and innovation and marketing stream. Moderate to strong negative correlations were revealed ($r = -.53$, $p < .05$ for innovation and marketing and $r = -.87$, $p < .01$ for IS). This is further evidence of the increasingly divergent conceptualizations in both fields, suggesting that with each new article the smart product concept becomes more ambiguous.

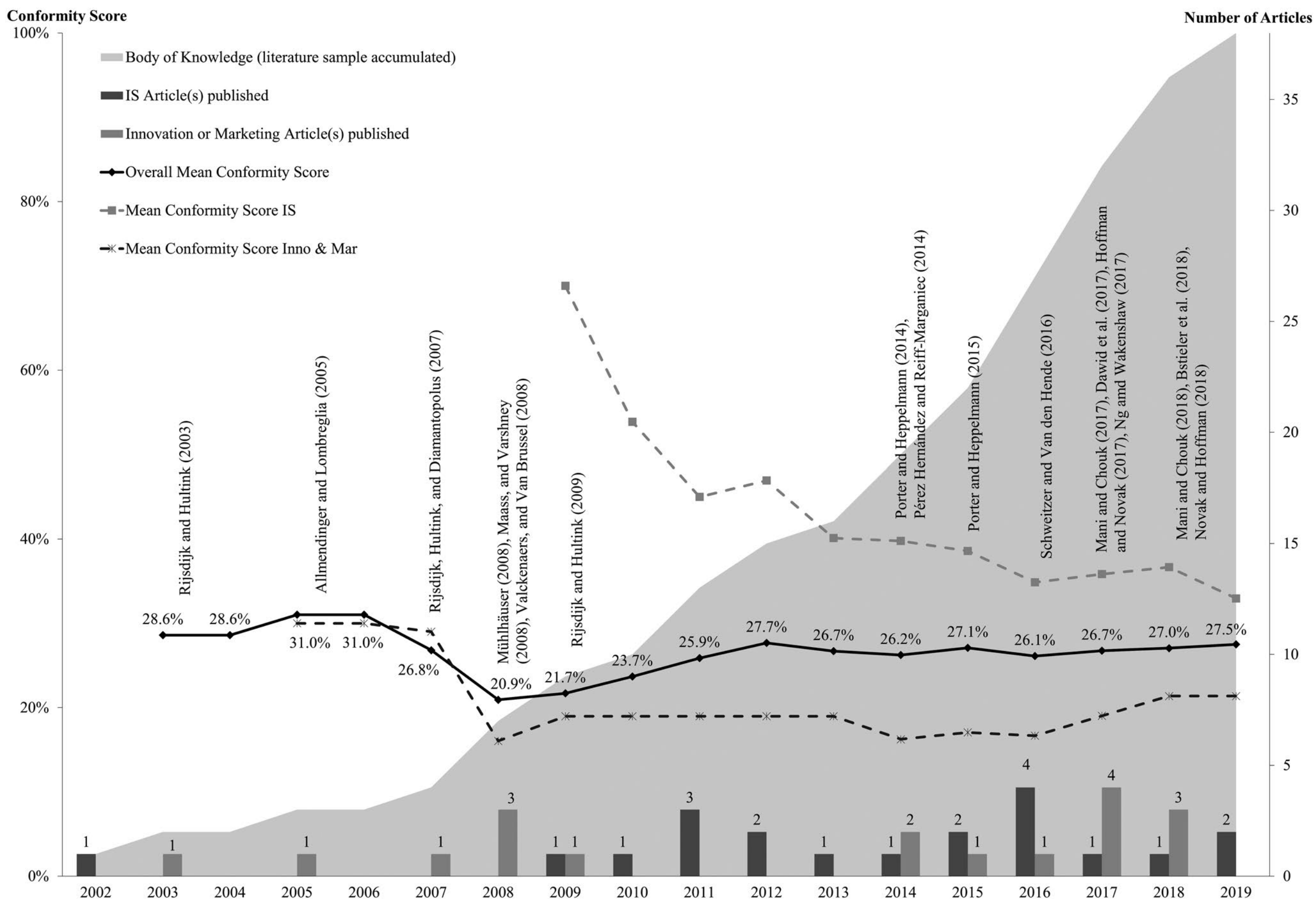

Figure 3. Development of Conformity Scores and Publishing Points of Smart Product Articles over Time

Emerging Product Archetypes

In the next phase of the analysis, the 16 capability-based criteria were synthesized. That is, rather than advancing a definition of smart products that consisted of 16 different criteria, these criteria served as a basis for deriving a comprehensive conceptual framework relating to smart products. The decision to synthesize the 16 criteria was based on two initial observations that emerged from the SLR. First, while all of the criteria are conceptually distinct and, in principle, independent from each other, it was also clear that smart products are typically based on specific combinations or configurations of these criteria. Second, while all of the criteria relate to the capabilities afforded by smart products, some of the criteria are more complex than others and/or act as prerequisites for other criteria. For instance, while *Reactivity and Adaptability* can be achieved through relatively simple rule-based software, *Reasoning and Decision Mak*ing or *Proactivity* require much more complex software enabled by artificial intelligence (AI).

These two observations suggest that smart products may be conceptualized as a range of archetypes that build on each other and are characterized by a particular configuration of defining criteria. To examine this possibility, a further round of coding with two professors, one postdoctoral researcher, and two student assistants was organized where the 16 capability-based criteria were intensively discussed and aligned with actual real-life products. In total, four different archetypes were identified, each archetype being defined by a particular orchestration of criteria: *(1) Digital*, *(2) Connected*, *(3) Responsive*, and *(4) Intelligent* (see Figure 4 or supplementary information Appendix B). These archetypes are organized in a hierarchical logic where a product will need to fulfill all the essential criteria of one archetype before it can move to the next archetype. That is, as archetypes increase, so does the versatility of the tangible components (i.e., the hardware), the complexity of the intangible components (i.e., the software), and the potential capabilities (i.e., the hardware and software working together). In this regard, capabilities can be considered as the bridge or threshold between the product and all outbound services and functions.

Hence, rather than providing a monolithic definition of smart products, the framework delineates different archetypes that constitute specific bundles of cyber-physical arrangements. In the following, each archetype is discussed against the background of the relevant literature and illustrated through numerous real-life examples. Table 3 illustrates the dynamic nature of the proposed framework by using historical and actual examples from the automotive industry that demonstrate how cars as cyber-physical bundles may fit different archetypes as they evolve.

Product Archetype 1: Digital

Defining criteria based on SLR and coding. IT Equipped, Data Storage, Data Processing and Analysis, Data Provision, and Transmission.

Conceptualization. A *digital product* is a discrete product equipped with hardware capable of processing information and supporting basic data management via its operating software. The digital product differs in nature from an analog product in that it is enabled by IT. This not only allows products to perform their traditional function, but also to process data, which enables a variety of additional capabilities (Porter and Millar, 1985). For example, a digital camera can not only take photos, but also display, arrange or delete them. Digital cameras, MP3-players or hi-fi systems are common examples of the digital archetype.

Capabilities and performance. The digital archetype marks the first evolutionary stage where analog products are augmented with IT capabilities. The embedding of IT allows products to pursue basic scripted operations such as to *retain* or *store data* as well as to perform *data processing and analysis*. In addition, data may be *provided and transmitted*, such as by retrieving data from a compact disc (CD) or USB drive to play music or by displaying pictures on the screen of a digital camera.

Real-life examples. As mentioned above, a digital camera is a classic example of the digital product archetype. Equipped with the necessary hardware and organization software, it meets all criteria to store, process, and provide data. However, to move along the archetypes of the framework and evolve into further developed versions, it will have to be furnished with connectors, sensors, actuators, and more

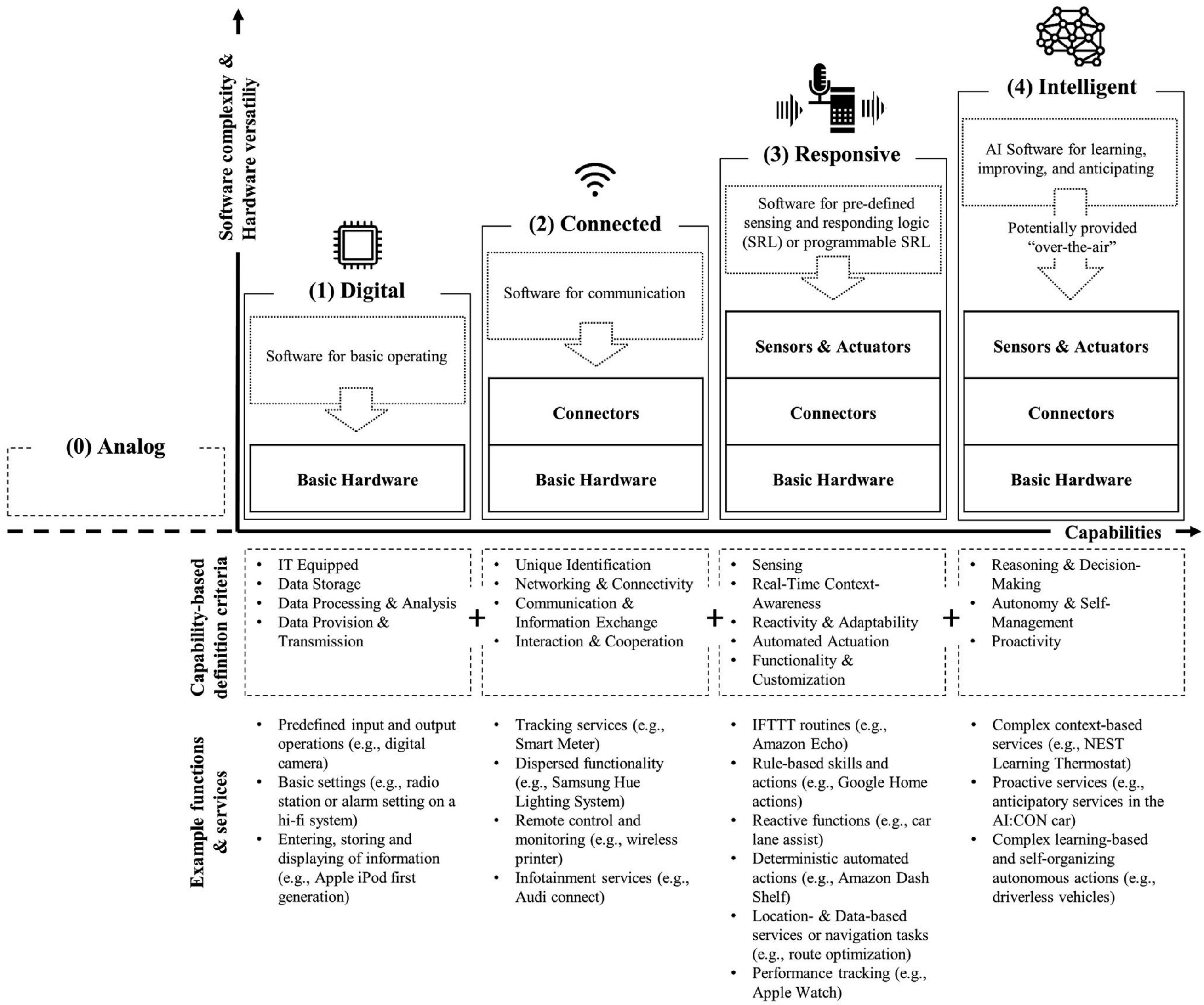

Figure 4. Framework of Smart Product Archetypes

powerful and sophisticated software. Hi-fi systems may be considered as an additional example of a digital archetype as they are able to store, process, and provide data, for example from CDs or USB drives, and may offer possibilities for basic settings such as alarm or reminder functions.

Product Archetype 2: Connected

Defining criteria based on SLR and coding. Unique Identification, Networking and Connectivity, Communication and Information Exchange, Interaction and Cooperation.

Conceptualization. A *connected product* is furnished with *connectors* and empowered by *communication software* so it may wirelessly connect to, engage, and create value with a larger network of entities such as the Internet of Things. The main value of the connected product results from the sending and receiving of data. In conjunction with other devices, a connected product can unfold its highest functionality. That is, by being embedded in an assemblage of products, connected products may create value via dispersed multifunctionality (Hoffman and Novak, 2017). Common product examples of this archetype are the Amazon Dash Button or the Philips Hue smart lighting system.

Capabilities and performance. Standing alone, a connected product may create no or only limited value. It is only in interaction with other units

Table 3. Cars as Cyber-Physical Bundles and their Evolution across Archetypes

Archetype	(1) Digital	(2) Connected	(3) Responsive	(4) Intelligent
Real-life example	• Audi A8 (first generation 1994–2002)	• Audi A8 with embedded Audi connect (since 2013)	• Audi A8 with embedded central driver assistance controller “zFAS” (since 2017) • Tesla Model S	• Audi AI:CON (planned market launch 2024) • Tesla Model S (since 2017)
Hardware	Basic hardware +	Connectors +	Sensors & actuators	-
Software	Software for basic operating	Software for communication	Software for predefined sensing and responding logic (SRL) or programmable SRL	AI software for learning, improving, and anticipating
Capabilities & examples	• Hardware and software for basic operating (e.g., engine control unit with engine control software or infotainment system) • Predefined input and output operations and basic setting of infotainment system (e.g., skipping song titles, rds-tmc, changing the volume) • Entering, storing, and displaying of information (e.g., entering and storing of radio stations, displaying of radio stations, the song played, or time indication on digital screens)	• Added connectors and interfaces for networking (e.g., SIM card and Wi-Fi hotspot to connect with a smartphone, infrastructure, or other vehicles) • Enabled through software for communication (e.g., Audi connect software) • Sending and receiving of data (e.g., remote monitoring of battery and fuel status, remote unlocking) • The connected car only unfolds its full potential in combination and cooperation with other entities (e.g., delivery of parcels into the car trunk through remote door unlocking via smartphone)	• Built-in connectors, sensors, and actuators allowing to sense and gain awareness (e.g., ultrasonic sensors in Tesla’s Model S allow the car to gain awareness of nearby cars and obstacles) • A responsive car is able to react and adapt to changes in the environment via software which operates according to a sensing and responding logic (e.g., lane assistance systems such as the Audi “active lane assist” or the brake assistants “pre sense 360” and “pre sense city”) • A responsive car contains all hardware requirements to evolve into a smart product via virtual upgrading (e.g., a software upgrade is needed to upgrade the Audi A8’s central driver assistance control units so that it becomes a software-controlled self-driving vehicle)	• Full hardware stack of a responsive product empowered through AI software (e.g., all recent Tesla models are equipped with an autopilot for full self-driving which can be activated over the air via a software upgrade) • Intelligent cars are able to react to environmental changes, to produce patterns, to reason, and to learn (e.g., the Argo AI software for self-driving Audi cars uses machine learning algorithms to continuously learn about the car’s environment and improve in-use) • Intelligent cars are able to anticipate events and make decisions (e.g., anticipate how other drivers and pedestrians will behave and act accordingly; or “PIA,” a personal intelligent assistant installed in the Audi AI:CON, which is able to anticipate passengers’ wishes)

that additional value is created, which may either be single-functional, such as in the case of the Amazon Dash Button, or multifunctional, such as with the Philips Hue smart lighting system. The latter may be characterized through its dispersed multifunctionality and refers to the mutual value creation through a set of distributed interconnected entities.

A fundamental virtue of the connected product is to share an iconic digital identity allowing for *unique identification* when networked with other devices (e.g., López, Ranasinghe, Harrison, and McFarlane, 2012; Meyer et al., 2009; Miorandi, Sicari, de Pellegrini, and Chlamtac, 2012). Such unique identification makes it possible to automatically detect, locate, and track devices throughout their life span and their activities (e.g., González García, Meana Llorián, Pelayo G-Bustelo, and Cueva-Lovelle, 2017; López et al., 2012; Meyer, Buijs, Szirbik, and Wortmann, 2014; Wong et al., 2002). Physically equipped with *connectors,* such a device is able to establish a *connection* and *network* with other entities and to communicate, cooperate, and interact. The respective connecting entities may vary and can include other devices (Kiritsis, 2011), users or systems in the environment (Langley et al., 2020; Meyer et al., 2009). These networking capabilities form the basis for the product's ability to *communicate and exchange information*, comprising the sharing of ideas and transmission of information flows between entities (e.g., Ng and Wakenshaw, 2017; Porter and Heppelmann, 2014, 2015; Touzani et al., 2018). Technically, communication may be realized via the whole array of available network technologies including wireless Internet technologies, Bluetooth or high-frequency RFID tags (López et al., 2011; Mayer et al., 2011; Whitmore, Agarwal, and Da Xu, 2015). The communication and information exchange between products allows devices to *interact* and *cooperate*, that is, to collaborate and jointly create value by working together in assemblages such as the Internet of Everything (IoE) (Hoffman and Novak, 2017; Langley et al., 2020).

Real-life examples. The Amazon Dash button can be considered as a typical example of a connected product archetype. Technically, this button is equipped with hardware and connectors that, when pressed, allow it to send an electronic Wi-Fi signal to Amazon to initiate an order process. Based on unique identification, the Dash button can be assigned to a specific user. Moreover, due to its networking, communication, and information exchange capabilities, user-specific order data can be transmitted between the user, the device, and Amazon to execute the order process.

The smart lighting system from Philips Hue is a useful example to illustrate how the value of connected products is created through their interaction in assemblages. The individual dispersed components such as the networkable Hue bulb or the Hue smart plug can only unfold their full functionality in communication and interaction with other devices such as the smartphone, the music system or the smart home assistant. In such assemblages, it is possible to remotely turn on the light, to align the music played with a corresponding light show or to operate the light via voice-control. In this way, different interconnected products and agents jointly create value.

Product Archetype 3: Responsive

Defining Criteria based on SLR and coding. Sensing, Real-Time Context-Awareness, Reactivity and Adaptability, Automated Actuation, Functionality and Customization.

Conceptualization. A *responsive product* is furnished with *connectors*, *sensors,* and *actuators*. This enables responsive products to not only connect to a larger network, but also to sense and gain awareness as well as to react to input signals and align with them. Responsive products are enabled by complex software allowing them to operate according to a sensing and responding logic (SRL). Mostly, responsive products are connected to other entities although this is not always necessary for them to function. This implies that, compared to the connected product, the functionality not only is no longer only dispersed, but also is inherent and directly attributable to the product itself. Many responsive products meet the basic hardware requirements and have "silent" components necessary to advance to the most advanced evolutionary stage, that of an intelligent product, but lack the required software abilities. Thus, responsive products are not necessarily "finished" upon delivery and may evolve into an intelligent product through digital upgrades or liquid software later in their life cycle (see also Ramaswamy and Ozcan, 2018). Common examples of this archetype are the Amazon Echo or the Audi A8 with central driver assistance control (zFAS).

Capabilities and performance. Products of the responsive archetype are equipped with sensor technology (e.g., car lane assistance systems such as the Audi "active lane assist" or the brake assistant "pre sense 360"), allowing them to *gather data and sense,* that is, to actively acquire or possess knowledge about the environment or about themselves (e.g., Allmendinger and Lombreglia, 2005; Baird and Riggins, 2016; Dawid et al., 2017; Porter and Heppelmann, 2015; Püschel et al., 2016). Sensing is a vehicle for liquefaction as it enables the creation of digital representations of processes and conditions, thereby mimicking "phenomenologically perceived reality" (Monteiro and Parmiggiani, 2019, p. 2). This, in turn, enables responsive products to gain *real-time context awareness* of the environment (e.g., location, moisture, sound, temperature or weight sensing) (Mayer et al., 2011; Porter and Heppelmann, 2015), of themselves (Gutierrez, Garbajosa, Diaz, and Yague, 2013; Mayer et al., 2011) or of business and legal constraints (Maass and Varshney, 2008). The volume, speed, and complexity of the data collected via sensors are constantly increasing, forming the basis for more and more high-level interactions (Chanson, Bogner, Bilgeri, Fleisch, and Wortmann, 2019; Püschel et al., 2016).

Moreover, these data streams allow firms to perform advanced data analytics or even apply "weak AI" to improve products while in use, determine the need for maintenance or offer a myriad of different functions such as location-based or navigation services (Huang and Rust, 2018; Meyer et al., 2009; Xu, Teo, Tan, and Agarwal, 2009). Furthermore, the captured data may feed into future product development cycles and may thus bear great potential for innovation management (Bstieler et al., 2018; Dawid et al., 2017; Holler, Uebernickel, and Brenner, 2016).

Sensing also enables devices to align their operations with changes in their surroundings, that is, to *react and adapt* (e.g., activation of car brakes if a pre-sense technology identifies an obstacle ahead) (Baird and Riggins, 2016; Mayer et al., 2011; Rijsdijk and Hultink, 2003). The most important constituent of reactivity and adaptivity is the *actuation* relating to the activation of different kinds of responding actions (Mani and Chouk, 2017). Together, this implies that devices not only sense and observe, but also pursue (re)actions based on observations (Rijsdijk et al., 2007). Actuation can take place either through physical built-in actuators attached to the product itself or virtual actuation. An example for the former is a vacuum robot that detects contamination via its sensors, followed by a suggestion to do a cleaning run which may then be carried out via built-in cleaning actuators. Virtual actuation can be illustrated via the Amazon Dash Shelf that detects the necessity of an order through the sensors embedded in the shelf and virtually initiates the process of informing the customer and actuating an order proposal. In general, automated actions taken by responsive products involve the automated carrying out of rule-based, if-this-then-that-type (IFTTT) operations. These operations also relate to early conceptualizations of product autonomy describing a product's independent actions without user interference (De Bellis and Johar, 2020; Rijsdijk et al., 2007). From today's perspective, however, this may be described as automation rather than complex, AI-based product autonomy (see the *Intelligent* archetype).

Building on this, products from the responsive archetype mostly work within the scope of clearly defined sets of operating parameters that allow distinguishing two types of responsive products at the level of *functionality*: They may either follow (1) a predefined sensing and responding logic (SRL) or (2) a programmable SRL. A product following a predefined SRL works within the scope of rather unidimensional operating parameters. An example of this is the Amazon Dash Shelf which operates in single-task sensing-acting programming. In contrast, products that follow a programmable SRL work on the basis of more versatile functionality and may even be programmed using skills, actions, routines, or the like. For example, Google and Amazon provide its customers with the opportunity to *customize* their Google Home or Amazon Echo via actions or skills and also provide developer platforms, allowing customers to program such IFTTT routines on their own. Maass and Varshney (2008) describe this as the "tailoring of products according to buyers' and consumers' needs and affects" (p. 213), enabling a highly personalized experience through the provision of tailored functions and services (Allmendinger and Lombreglia, 2005; Maass and Varshney, 2008).

Since responsive products often fulfill all hardware requirements for the highest hierarchy level of a smart product, they might evolve relatively easily into an intelligent product. This may be realized "over-the-air" (OTA) via digital upgrading or liquid software (Taivalsaari, Mikkonen, and Systa, 2014).

Real-life examples. The Atomic Connected ski boot is a typical example of a responsive product that enriches the skiing experience with the help of large amounts of data. Motion and acceleration sensors attached to the back of the ski boot form the core of the system. The system tracks overall ski performance, records data such as slope inclination and speed, counts downhill runs, turns, distances, and elevation as well as registers how well one is standing on the ski. The device uses the boot's sensory feedback to generate and actuate smartphone notifications helping the user to improve skiing in terms of smarter, safer, and better skiing.

Another product that can be considered as responsive is the Amazon Dash Shelf. Relative to its phased-out predecessor, the Amazon Dash Button, the Dash Shelf not only is equipped with hardware and connectors, but also with sensors. These sensors use virtual actuators to trigger an order as soon as the weight of the product to be ordered (e.g., toilet paper, coffee cups, office supplies) falls below a certain critical weight threshold. Based on software enhancements it may even evolve into an intelligent product that behaves in an anticipatory manner, for example by predicting demand and delivering accordingly (see also Venkatesh, 2018).

Product Archetype 4: Intelligent

Defining criteria based on SLR and coding. Reasoning and Decision-Making, Autonomy and Self-Management, Proactivity.

Conceptualization. The *intelligent product* is a device that is capable of learning, anticipating, and acting independently. An intelligent product is equipped with the full hardware stack of a responsive product and also features the requisite powerful AI software. These software capabilities allow the product to connect to a larger network or to react to environmental changes as well as to produce patterns, to reason, and to learn—in short, to embody intelligence. In this manner, intelligent products are not only software-enabled, but also software-controlled, allowing them to anticipate events and to autonomously activate appropriate initiatives. Examples of this archetype are the NEST Learning Thermostat or self-driving vehicles such as the Audi AI:CON or e.Go Mover.

Capabilities and performance. The capability to *reason and make own decisions* is at the core of what makes a product intelligent (Kortuem et al., 2010; Rijsdijk and Hultink, 2009; Valckenaers and van Brussel, 2008). In this regard, López et al. (2012) observe that "smart objects are those objects that can make decisions about themselves and their interactions with external entities" (p. 295). Reasoning and decision-making are interrelated with a product's *autonomy and self-management,* describing "that a product does not need human intervention but instead takes over on its own" (Rijsdijk and Hultink, 2003, p. 206). Whereas responsive products may automate sets of deterministic functions and follow an IFTTT-type logic, intelligent products feature the highest levels of product intelligence, allowing them to learn, evolve, and act on their own "agenda" (De Bellis and Johar, 2020; Rijsdijk et al., 2007).

Technically, this can be achieved via the integration of advanced forms of AI, that is, so-called "strong AI" (De Bellis and Johar, 2020; Mühlhäuser, 2008; Verganti, Vendraminelli, and Iansiti, 2020). More precisely, intuitive intelligence enabled by deep learning and artificial neural networks may allow devices to reason creatively and to learn effectively from new situations as well as to adapt and to take *autonomous* actions as the environment changes (Huang and Rust, 2018; Novak and Hoffman, 2018). Such strong AI allows intelligent products to rapidly absorb and learn from growing, complex data sets, potentially exceeding the performance of human intelligence. A current application that has taken AI integration and autonomous decision-making to extremes is the AlphaGo Zero by Google's AI group DeepMind (Silver et al., 2017). Apart from this hi-tech niche, the nascent era of self-driving cars has increased the focus on AI-based technology that can take autonomous action (Dawid and Muehlheusser, 2019; Schweitzer and van den Hende, 2016). Vehicles that apply highest levels of product intelligence when facing complex circumstances or effectively adapt to complex situations by taking *autonomous* actions will soon be more than a futuristic vision (Dawid and Muehlheusser, 2019; McGee, 2019).

In a related vein, intelligent products may engage in *proactive* behavior through predictive analytics.

Compared to responsive products, embedded product intelligence enables intelligent products to predict events via early warning systems or anomaly detection (Breuker, Matzner, Delfmann, and Becker, 2016). This allows them not only to react, but also to engage in proactive behavior (Bolton, 2018; Porter and Heppelmann, 2014). In this manner, driverless cars, for instance, may foresee potential risks or hindrances even before they actually appear and take appropriate countermeasures. The combined strength of analytics, statistics, and machine learning will enable increasingly accurate predictive models of the future that will enhance the value provided by future smart products. This may eventually help to establish and strengthen long-lasting customer-firm relationships across various branches and industries (Bstieler et al., 2018; Gunasekaran et al., 2017; Porter and Heppelmann, 2014).

Real-life examples. The NEST Learning Thermostat is a current example of an intelligent product. Using the auto-schedule function, it is able to learn by itself which room climate its users like at different periods of the day. After a couple of days of learning, the NEST Learning Thermostat develops an intuition about its users and anticipates habits via predictive analytics, automating the regulation of the indoor climate accordingly. Using the Home-Away assist function, the NEST Learning Thermostat can help save energy by autonomously switching to an eco-temperature when it notices that nobody is at home.

An additional example of an intelligent product is the minibus e.Go Mover. Through sensors and embedded AI for vehicle-to-infrastructure use, the e.Go Mover leans about the environment in its area of application. After spending a few weeks of training, the e.Go Mover develops a complex understanding of its surroundings and can adapt to it as well as move around independently.

Discussion, Contribution and Future Research

This research aimed to integrate different perspectives on smart products and to enhance the understanding and observability of smart products as an *epistemic object*, thereby creating a common ground for future research. To this end, an SLR and a bibliometric analysis of the current literature were conducted. The SLR provides a representative state-of-the-art snapshot containing—to the best of the authors' knowledge—all relevant, peer-reviewed articles on smart products. In addition, the criterion-based bibliometric approach allows for comparisons of an interdisciplinary set of articles based on their underlying conceptualizations. This approach illustrates how the concept of smart products has evolved within and across disciplines. In this regard, the analysis also addresses the repeated calls for research beyond disciplinary boundaries and the application of new approaches and methods in emerging topics such as intelligent technologies or IoT (e.g., Bstieler et al., 2018; Mani and Chouk, 2018; Noble and Spanjol, 2019).

Both the SLR and the bibliometric analysis provide robust support for the initial observation of an inconsistent body of knowledge within and across disciplines. Against this background, 16 commonly used criteria to define smart products were extracted and synthesized into a conceptual framework delineating four different smart product archetypes. Obviously, one important question concerns the generalizability of the framework across different product categories and research disciplines. While this is, to a certain extent, an empirical issue, there is much to suggest that the framework is generalizable. First, the literature search was broad in nature and the articles in the sample reflected a wide variety of research disciplines, academic journals, and product categories. In other words, the "raw material" for the analysis was collected with the idea of developing a generalizable framework in mind. Second, as stated earlier, when developing the archetypes, special attention was paid to aligning these archetypes with a diverse set of real-life examples, including the Amazon Dash button, the Philips Hue smart lighting system, the Atomic Connected ski boot, the NEST learning thermostat, and the Audi AI:CON.

Importantly, the framework also addresses the limitations of the current literature on smart products identified in the introduction of this article. First, by proposing distinct archetypes, the framework tackles the "one-size-fits-all" problem of summarizing inherently different products under one vague, collective term. Second, the archetypes delineate authentic, real-life orchestrations of capability-based definition criteria while also using a standardized terminology. This, in turn, will help to create a common understanding of the defining properties of smart products. Third, the framework distinguishes smart products from their outbound services, functions or embedded ecosystems, thus, strengthening the understanding of smart products as distinct cyber-psychical bundles.

In sum, the framework provides a much-needed structure to the existing body of knowledge as a whole that will enable scholars to analyze smart products at a more fine-grained level of analysis and to situate their findings in a wider conceptual context. Apart from this organizing function, the framework also contributes to the literature by pointing to three more specific themes associated with smart products. The following sections will review each of these themes and discuss promising possibilities for future research that arise from each theme and that may further enhance the body of knowledge on smart products.

Smart Products as Archetypes

As mentioned above, this article advances an interdisciplinary framework that distinguishes different types of smart products based on the complexity of their hardware and software. This framework contributes to the literature by providing structure to a research domain that is yet standing on feet of clay and by allowing for systematic integration of the smart product concept into related concepts such as the IoT, IoE or smart services. Moreover, the framework emphasizes that smart products are not monolithic objects but rather dynamic entities that may evolve from one level to the next, for example, when a product evolves from a connected product to a responsive product or even to an intelligent product through hardware or OTA software upgrades. In this sense, the framework also suggests that smart products may never truly be "finished" in the strict sense of the word. This conceptualization opens up at least two important broader questions.

First, how will products move along the archetypes and/or how extreme should OTA upgrades be? Real-life examples show that the progression of products does not necessarily follow a gradual logic, but that products may skip development stages, terminate at an early stage (e.g., the idea of a light bulb that is capable of reasoning and decision-making does seem strange) or move forth and back multiple times during their lifespan (e.g., upgrading or canceling of the Tesla Premium Connectivity subscription). Importantly, a product's progression through different stages may also relate to a company's overarching strategy and products that are more software-intensive typically provide firms with greater leverage in this regard. For instance, companies can end the support of older hardware for new software innovation cycles or, worse, use software upgrades to effectively degrade the performance of a device in order to push for the purchase of new hardware (Agnew, 2018). Against this backdrop, a better understanding of the mechanisms and rationales underlying the transitions of products along the archetypes and how companies manage these transitions can be of great value.

In addition, from a consumer perspective, virtual OTA upgrades that happen overnight may not always be perceived as beneficial. Previous research indicates that consumers may feel overwhelmed by innovations that deviate too strongly from existing category norms because such innovations may challenge their mental schemes, cause considerable uncertainty, and incur high learning costs (e.g., Landwehr, Wentzel, and Herrmann, 2013; Moreau, Markman, and Lehmann, 2001; Mugge and Dahl, 2013). As a result, they may prefer moderate degrees of innovation over radical ones. Consequently, it is important to examine the potential positive and negative effects of radical OTA upgrades from a consumer perspective. Specifically, such studies may want to investigate (i) which functions or capabilities should (not) be passed on to certain smart products regardless of the technological feasibility and (ii) to what extent OTA enhancements should be emphasized or downplayed prior to product launch.

Second, if smart products are never truly "finished," this obviously raises the question of how the proposed framework will evolve and what the next future archetype may look like. A possible scenario would be that the next developmental stage occurs through the infusion of empathetic AI, leading to an "empathetic product" archetype (Huang and Rust, 2018). Audi, for example, already considers the AI:CON as being empathetic, although the embedded AI "PIA" does not possess any real empathy in the sense of genuine affection. However, future empathic products could not only be intelligent and offer personalized functionalities, but could also take on social, emotional, or relational tasks. They could thus not only fulfill the function of a product, but may potentially also act as a full-fledged interaction partner. Extending the current framework with an empathetic product archetype also raises the question of how such a product should be designed to appeal to consumers and whether it should, for example, be anthropomorphized. In this respect, recent research on service robots points to the positive as well as potentially negative effects of equipping smart technologies with a humanlike appearance (Mende, Scott, van Doorn, Grewal, and Shanks, 2019; van Doorn et al., 2017).

Smart Products as Distinct Cyber-Physical Bundles

The framework also contributes to the literature by pointing to the bundled nature of smart products. That is, by clarifying that smart products consist of both tangible and intangible components, the framework helps to separate smart products from the services and functions they provide and to analyze their role in a wider network. For instance, CARV is a smart product that can be used to supplement conventional ski boots with digital coaching to improve one's skiing style. CARV consists of a bundle of hardware and software components that can be broken down to analyze the extent to which each component contributes to value creation: A pressure sensor plate is placed inside the ski boot and connected by cable to a small box attached to the boot. CARV uses components that sense the user's style of skiing and positioning (sensor plates), transmits this information (Bluetooth connectors), and applies embedded AI (AI software) to provide personalized suggestions (autonomy) for performance improvement. This example not only illustrates that smart products consist of complex cyber-physical arrangements where different components need to generate as well as consume information to create value (Hoffman and Novak, 2017); it also shows that the value generated by a product's intangible components is often anchored in its tangible components. Hence, the framework emphasizes the importance of the material aspect of smart products.

Again, this conceptualization of smart products points to further questions that may need addressing in future research. While the arguments outlined above clarify how the physical components of a smart product contribute to the creation of *functional* value (i.e., by working with the product's software-based components), there is little research that examines if and how physical components may enhance a product's *emotional* value. As discussed in the introduction, relationships with customers are frequently formed on the basis of a physical device (e.g., an iPhone or Amazon Echo), suggesting that the device's role may also be that of creating a socio-material connection. In this regard, research in marketing has emphasized that physical possessions form part of a person's extended self (e.g., Belk, 1988, 2013). People often feel that their possessions define who they are, as a result of which they will develop strong feelings of attachment. However, recent studies have also found that consumers may find it more difficult to relate to their digital possessions and may be less likely to develop feelings of psychological ownership for them (Atasoy and Morewedge, 2018).

Against the background of these findings, it seems possible that the physical, material components of a smart product are more than an "enabler" of the product's software-based capabilities; they may also allow consumers to develop an emotional connection and feelings of ownership for the product. Building on this idea, it will also be important to understand whether these feelings of ownership extend to the services rendered by the smart product or even to the wider ecosystem in which the product operates. Arguably, feelings of attachment and ownership are exclusive to the material product so that consumers feel less ownership for the services provided by the product. Research on access-based consumption provides some support for this notion (Bardhi and Eckhardt, 2012; Eckhardt et al., 2019; Schaefers, Wittkowski, Benoit, and Ferraro, 2016). For instance, Bardhi and Eckhardt (2012) found that users of access-based services (e.g., car-sharing services such as Zipcar) do not "experience perceived ownership and avoid identification with the accessed object of consumption" (p. 894). On the contrary, it may also be possible that feelings of ownership spill over to the product's intangible components, suggesting that the material nature of smart products may help to create a connection to otherwise abstract entities such as skills, apps, services, and functions (Scharfenberger, Wentzel, Warlop, and Tomczak, 2014). Hence, future research may not only want to examine *if* consumers develop feelings of ownership for smart products, their associated functions and services, and their wider ecosystems, but also *under which conditions* this is more or less likely to happen.

Value Creation through Smart Products

The distinction between the physical, tangible and the software-based, intangible properties of smart products also contributes to the understanding of how smart products create value for customers. In the digital age, the future may belong to firms that bring products to market that can be substantially improved and “re-architected” after the initial sale of the actual material product (see, for example, Tesla). That is, in an era where the dividing line between a smart product and a created function or service may become blurry, the role of a product may increasingly be that of a platform or launchpad for a continuous stream of software-based service innovations provided over-the-air. Thus, customer relationships will likely become more long-lasting with the same material product, while the product experience may remain dynamic and generative through continuous upgrading.

Recent research has already started exploring this issue. For instance, Ramaswamy and Ozcan (2018) point to the dynamic and generative nature of digitalized offerings where value is continuously co-created in evolving networked arrangements of products, agents, processes, and interfaces. Moreover, Verganti et al. (2020) briefly discuss the problem of the limited adaptability of the product due to its material nature, on the one hand, and the increasing modularity through “softwarization” of functions and implementation of “silent components,” on the other hand. Besides these general considerations, however, a more in-depth understanding of the ideal architecture of smart products as cyber-physical bundles is needed. To establish a lasting relationship with customers, it will be increasingly important to hit the “sweet spot” of a product that is highly advanced and long-lasting on the material side, while also having the greatest possible modularity and adaptability on the software side. Only if this balancing act is successful, will OTA upgrading unleash its full potential and will companies be able to satisfy customer needs through a relatively stable material platform, on the one hand, and a continuous stream of software-based innovations, on the other hand.

This notion, in turn, suggests at least three other interesting areas for future research. First, from an innovation management perspective, the tangible and intangible properties of smart products may require differently structured development processes. The material components of a smart product may need to be developed with a longer timeframe in mind (because the material platform is meant to last a long time), whereas the software-based components may benefit more strongly from an iterative approach where new features are continuously developed, launched, tested, and implemented (Paluch et al., 2020). Hence, this raises the interesting question as to how the diverging demands of long-lasting materiality and fast-paced software need to be coordinated both within a single firm as well as across the wider ecosystem a smart product may be part of.

Second, the prospect of being able to combine longer lasting usage cycles on the material side with shorter innovation cycles on the software side presents a promising research avenue from an ecological perspective. So-called eco-innovative product designs are becoming increasingly relevant as consumers’ environmental concerns grow (Paparoidamis, Tran, Leonidou, and Zeriti, 2019). In this regard, it may be worthwhile to examine if not only the software-based components of smart products can be designed and provided in a modular fashion, but also the hardware components (e.g., sensors, actuators, connectors, etc.). While early attempts to develop modularized smart products have failed (see, for example, Project Ara, Google’s discontinued attempt to develop a modular smartphone), more recent attempts appear to be more promising (see, for example, Insta360’s ONE R camera, a modular camera). Arguably, hardware modifications or upgrades to existing smart products may even be performed at the customer’s premises using 3D printing, thus, rendering the product life cycle more ecological and resource-efficient (Ford and Despeisse, 2016; Rindfleisch and Malter, 2019; Wiecek, Wentzel, and Erkin, 2020).

Third, while the previous arguments indicate how companies can *create* value for customers through the architecture of their smart products, more research will be needed to also understand how they can *extract* value. That is, if the material side of smart products is indeed designed as a base from which software-based innovations are launched, then, this raises the important question as to how the base and the software-based functions should be priced (Kannan and Li, 2017). Arguably, rather than setting a fixed product-based price, two-part pricing models (Iyengar, Jedidi, and Kohli, 2008), subscription-based pricing models (Jain and Kannan, 2002) or even freemium-based pricing models (Lambrecht and Misra, 2017) may be more in line with the continuous stream of innovations stemming from smart products and may also allow companies to extract greater value for their offerings. In this regard, the framework can be used to decompose value creation at the level of individual product components and functions, thus, allowing companies to derive more effective pricing models.

Conclusion

The smart product is a rapidly evolving and multi-faceted concept, developing at the same speed as IT and new product development move forward. Taking stock of this work, one can see that smart products are currently being studied by scholars from different fields using diverging perspectives that suit their research objectives. However, this has led to a scattered and patchy body of knowledge. After reviewing the major perspectives on smart products and quantifying their development across time and different disciplines, this article presents a hierarchical framework that delineates four different archetypes of the smart product periphery.

Like any research, this study is subject to certain limitations. Importantly, the search process with regard to the search string as well as the assembling of the literature sample and the extraction of the defining criteria for smart products were based on subjective assessments. As a consequence, personal interpretations and assessments of relevance could have affected the aggregation and coding of the criteria. In addition, although the literature search was based on keywords, there is still the possibility that this search missed a portion of the relevant literature, especially with regard to publications not listed in the WoS database. Lastly, a further limitation might stem from the sampling procedure in the form of a broad funnel instead of taking a narrow focus on a specific product category or market. These issues are, however, common to SLRs (Córdoba, Pilkington, and Bernroider, 2012; Webster and Watson, 2002).

Notwithstanding these limitations, the framework emerging from this study provides an important contribution to research on smart products. That is, it does not only clarify the understanding of smart products as an epistemic object, but may also lay the ground for more systematic research that will yield a cumulative body of knowledge.

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